

FAA CLEEN II Technologies

Rolls-Royce CLEEN II Low NOx Combustor Program, Unlimited Rights/Public

Presented to: CLEEN Consortium, Atlanta GA

By: Duane Smith, Sr. Combustion Aero Engineer

Date: November 2, 2016

<i>Jurisdiction</i>	<i>Export Classification Rating</i>	<i>Date</i>
United States	NO TECHNICAL DATA	10/25/2016 by BDB

Trusted to deliver excellence



Elevator Speech

The Rolls-Royce CLEENII Combustion Development program will advance the state-of-the-art in Rich-Quench-Lean (RQL) combustor performance, enabling significant reduction in NOx pollution for advanced engine platforms with aggressive turbine entry temperatures. The comprehensive approach incorporates advanced fuel injection and wall cooling technologies coupled with implementation of enhanced mixing methodology. A rigorous development plan with progressive validations through component rig and system level testing will mitigate risk and develop a combustion platform for engine evaluation. We will build upon prior Rolls-Royce development to demonstrate emission reductions in two phases with a near-term configuration targeting NOx emission levels 50% below CAEP/8 limits and a final configuration with NOx level 65% below CAEP/8.

Program objectives

- Offer leading technologies in areas of cycle efficiency improvement and emissions reduction that work together in future engine architectures to provide significant contributions toward the CLEEN II goals
- Improve RQL combustion technology capabilities with application of advanced technologies, new design methods, research of fundamental principles, and validation through component and full-scale system testing
- Provide combustion capability assessment at TRL6
- These environmentally friendly technologies target component and system optimization, and will position Rolls Royce for fleet engine retrofit opportunities as well as new product applications, leveraging the CLEENII investments for reducing emissions over a multiple engine platforms

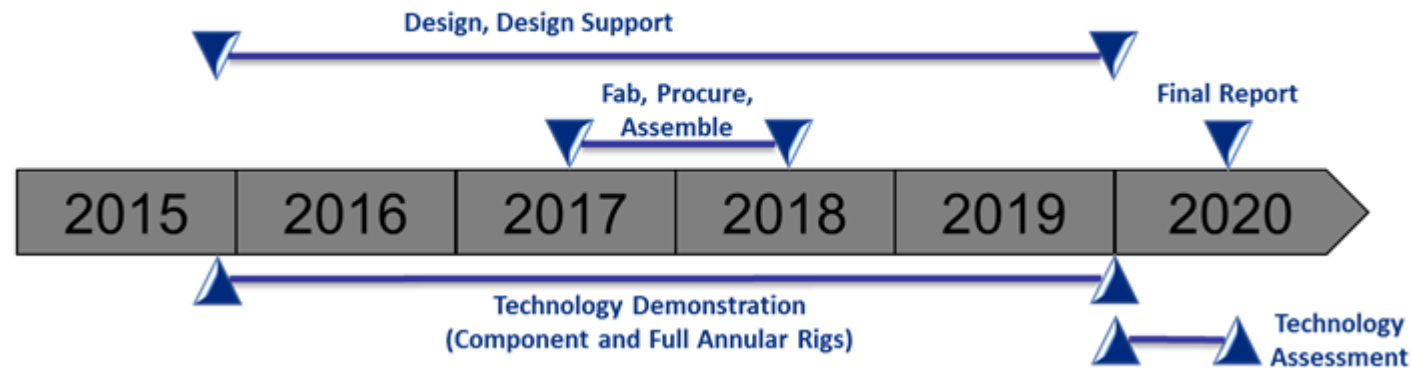
Approach

- Integrate low emission enabling technologies such as:
 - Advanced wall cooling
 - Innovative fuel injection
 - Novel mixing aerodynamics
 - Optimized combustor shape
- Conduct laboratory testing to develop and demonstrate low emission performance
 - Utilize component combustion rigs to capture detail performance metrics to confirm design intent
 - Conduct full-scale combustion system testing using a full-scale rig and demonstrate TRL6 with a technology demonstrator engine

Program Status Schedule

5

Advanced RQL Low NOx Combustion System



Rolls-Royce

CLEEN Technologies

6

CLEEN Technology Name	Goal Impact	Benefits and Application
Advanced RQL Low NOx Combustion System	NOx Reduction	Develop and demonstrate significant NOx reduction with advancing combustion technology that is suitable for emerging high pressure ratio, small core engines

Project Year 1 Achievements

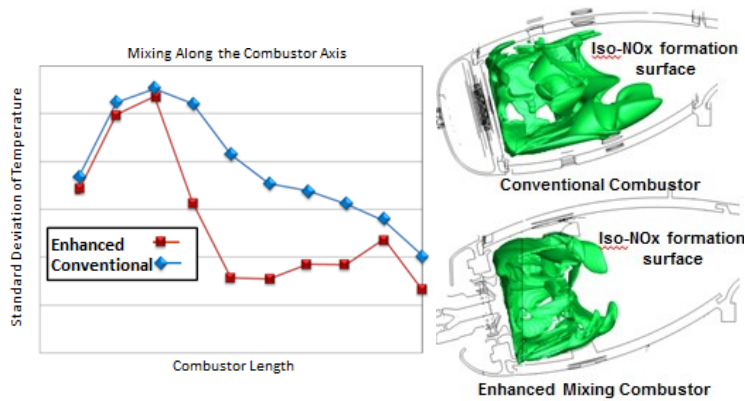
7

- Kicked off combustor design technical work
- Identified initial full annular rig fuel injector design with atmospheric and TRL3 demonstration tests
- Refining system design with CFD tools and a cold flow rig to benchmark external aerodynamics
- Conducted CDR for full annular combustion system rig
- Established combustor design with key manufacturing processes for first full annular rig test unit

Project Year 2 Plans

- Complete test protocols with cold flow rig
- Commission full annular rig and complete test of prototype demonstrator engine combustion system
- Fuel injection development
- Assess rig results, and integrate lessons learned with design improvements

Advanced RQL Low NOx Combustion System



Rolls-Royce

Anticipated Benefits:

- Significant NOx reduction
- Negligible operability impact
- Highly cost effective
- Technology capable of broad product insertion
- Advanced wall cooling and manufacturing technology

Risks/Mitigation Plans:

- Rigs are planned to manage risk and provide
 - Analysis benchmarking
 - Component and system development

9

Objectives:

- Improve RQL combustion technology capabilities with application of advanced technologies, new design methods, research of fundamental principles, and validation through component and full-scale system testing
- Substantial NOx reduction to emissions levels 65% below the CAEP8 guidelines

Work Statement:

- Design an enhanced rapid quench, rich burn combustion system and demonstrate system performance with technology insertions such as advanced wall cooling, innovative fuel injection, and novel mixing aerodynamics



Rolls-Royce

Accomplishments/ Milestones:

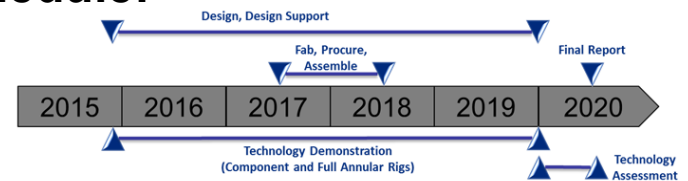
June-Aug 2016

- Thermal fatigue testing of combustion liner material
- Fuel injector atmospheric testing
- CFD analysis of combustor flow fields

Sept/Oct 2016

- External flow rig assembled and testing initiated.
- CDR held for full annular rig.

Schedule:



Rolls-Royce